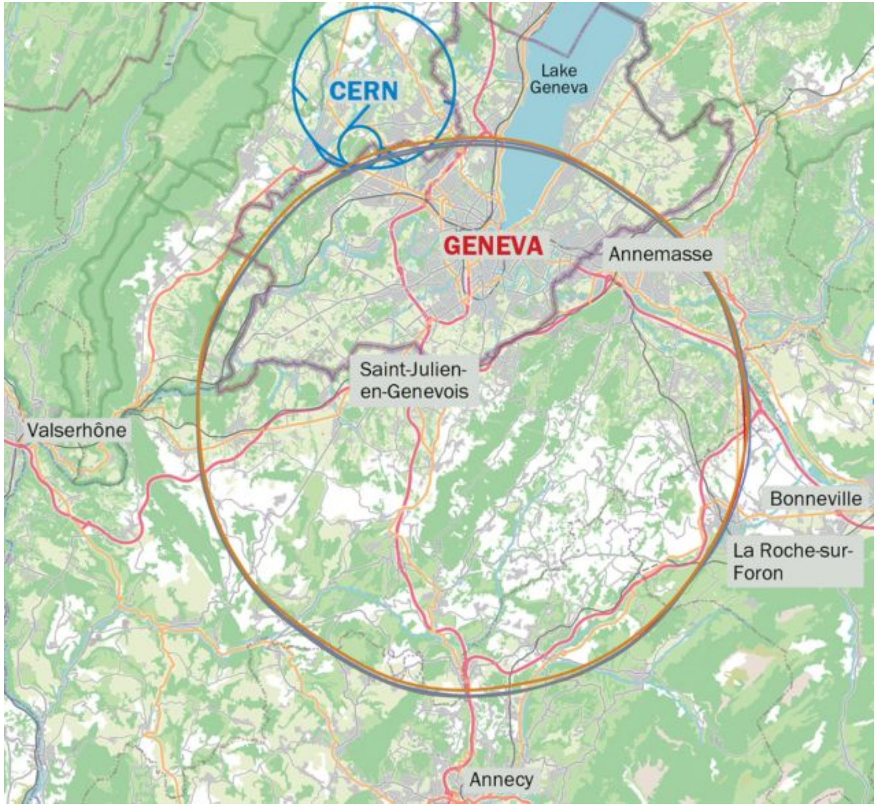
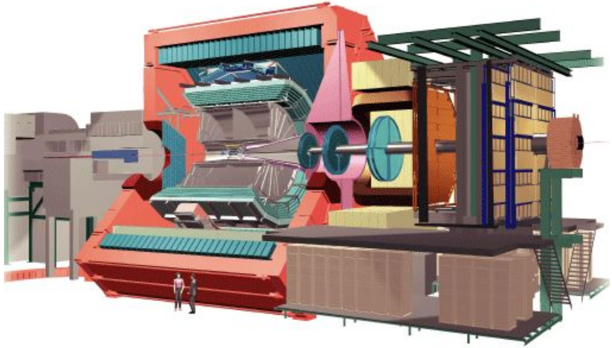
ATLAS

Future Circular Collider

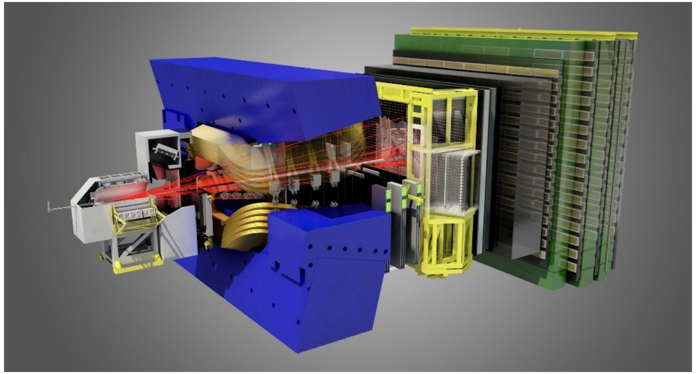
- Ongoing work towards the Future Circular Collider (FCC) at CERN
- 90-100 km long
  - Limited by geography
- ~100 TeV collision energy
- LHC will be in acceleration chain
- At least 30 years expected for design and construction



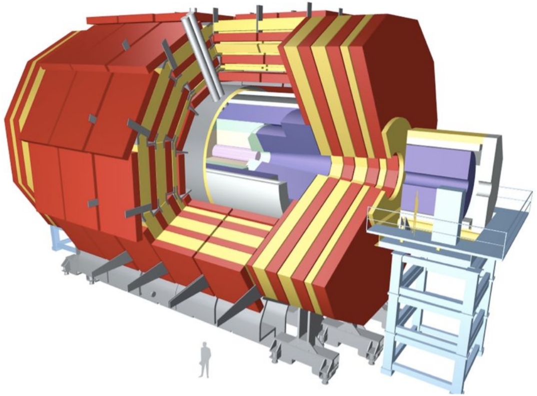
Main LHC Experiments



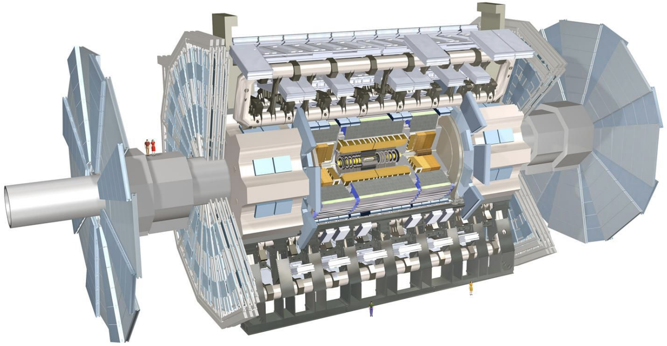
ALICE



LHCb



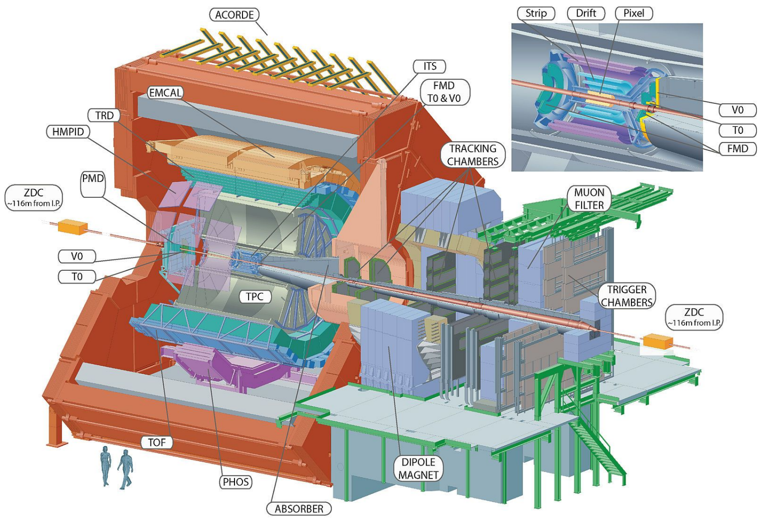
CMS

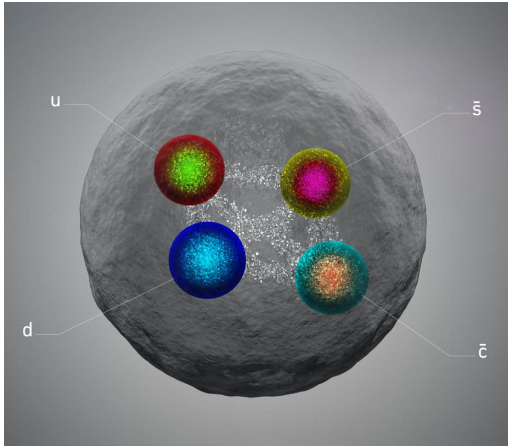


ATLAS

ALICE

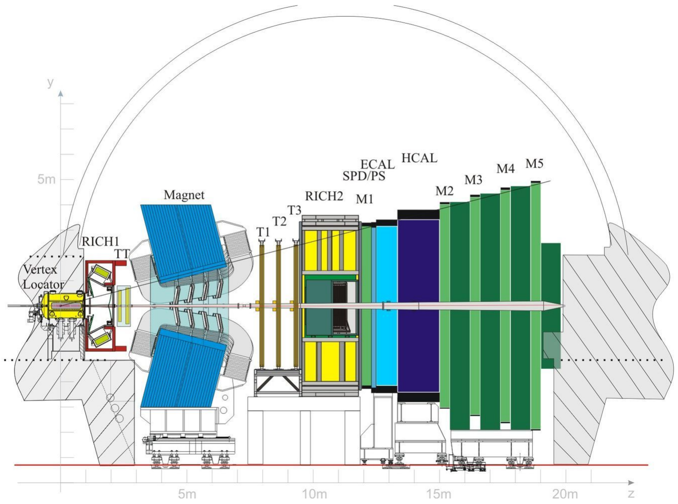
- A Large Ion Collider Experiment
- Specialized for Pb-Pb collisions
  - Also uses p-Pb collisions
- Goals are to improve understanding of QCD
  - Quark-gluon plasma
    - State of matter in which free color charges exist
  - Quark deconfinement
    - Existence of quarks outside of bound states
- Many discoveries including new tetraquarks and pentaquarks





LHCb

- Large Hadron Collider beauty experiment
- Focused on studying properties of B-hadrons
  - Hadrons containing a b quark
- Numerous measurement goals
  - B-hadron branching ratios
  - Asymmetries in flavor-changing neutral currents
  - CP violation in B-hadron decays
    - Could explain matter/anti-matter asymmetry
  - Other B-hadron decays

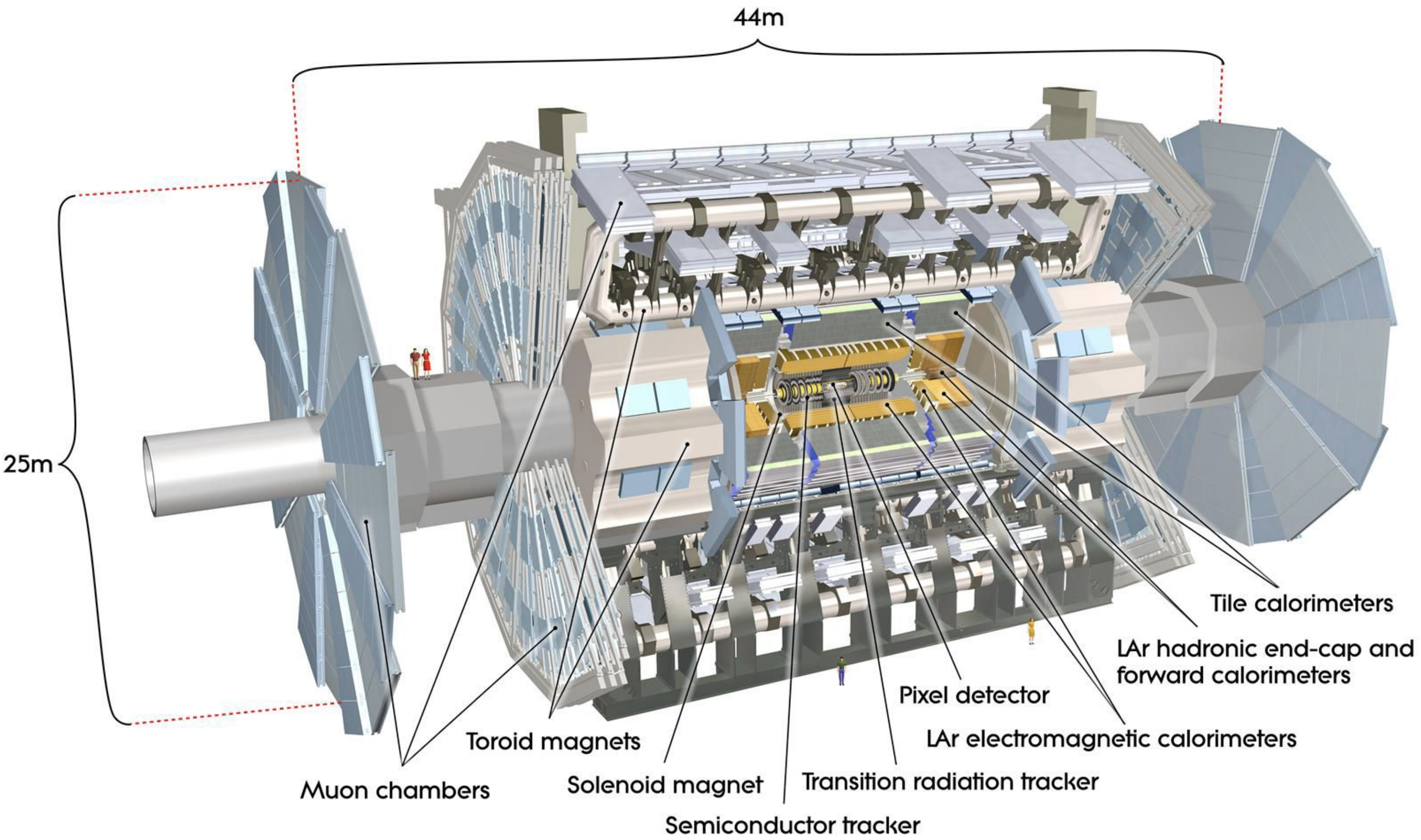


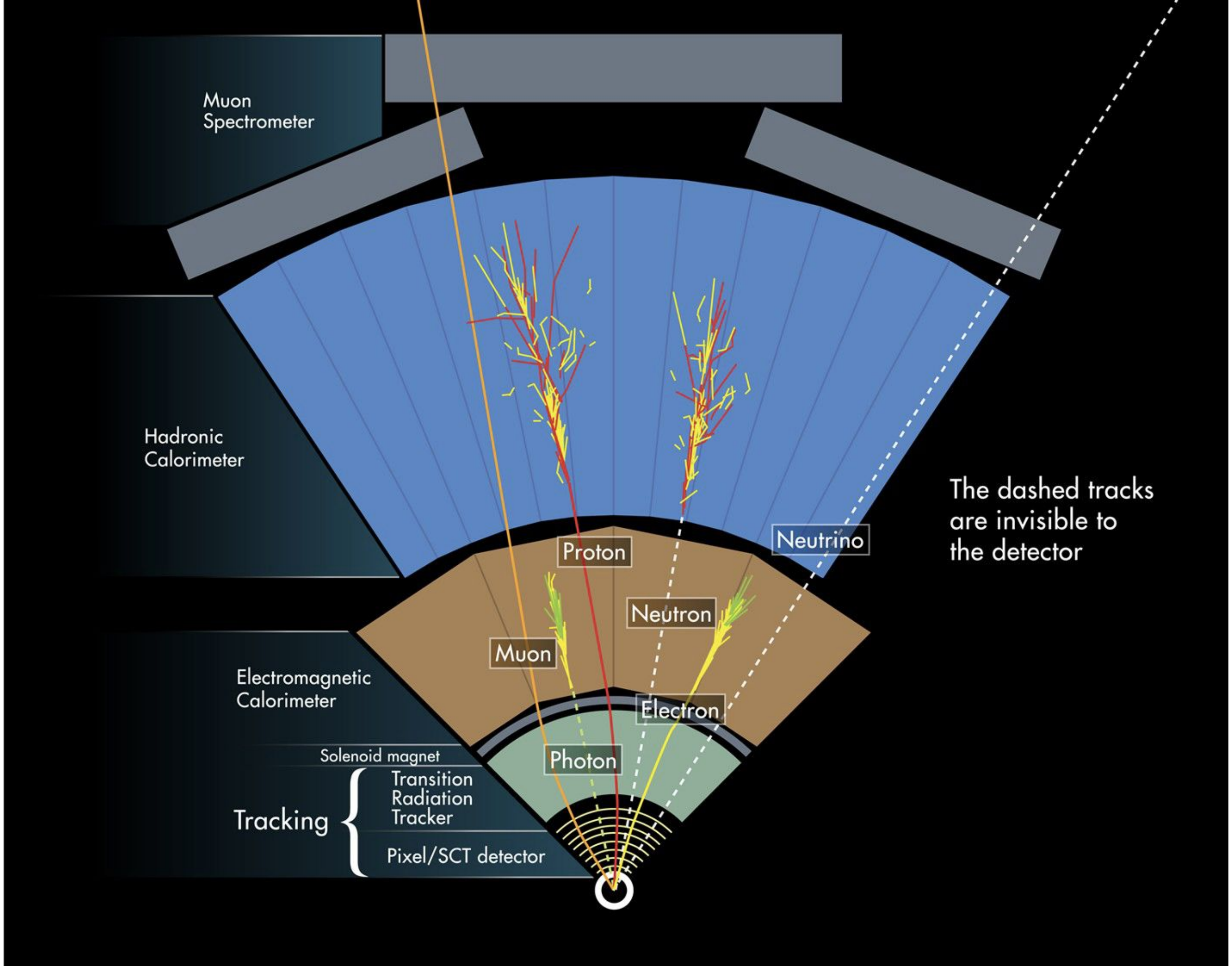
ATLAS and CMS

- A Toroidal LHC ApparatuS and Compact Muon Solenoid
- General purpose experiments
- Designed to search for generic particle discovery and measurements
- Similar designs and physics goals
- Primarily focused on pp collisions, but also make use of heavy ion collisions
- Friendly competition for discoveries
  - Simultaneous observation of the Higgs boson
  - Agreement to inform each other of major discoveries in advance of public announcement
  - Harmonization of some techniques to enable comparisons and combinations
- More details shortly

Other LHC experiments

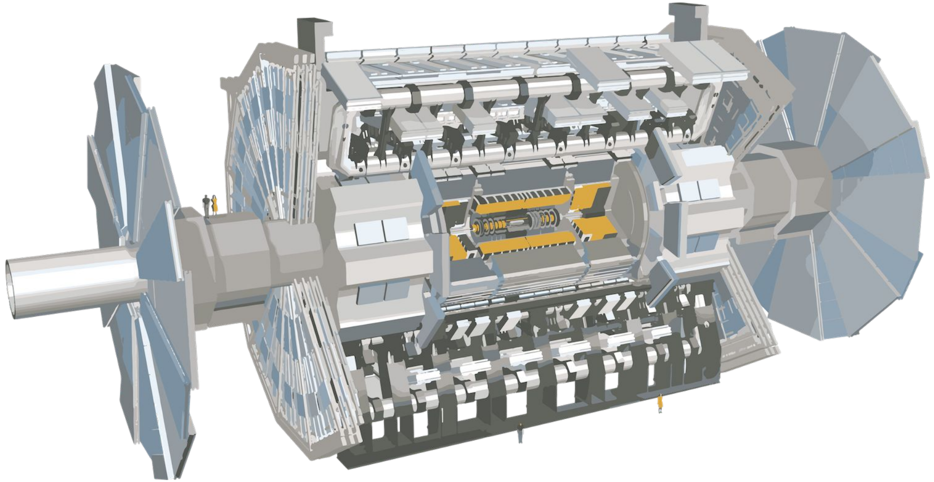
- LHCf
  - Measurement of particles traveling close to beamline
- MATHUSLA and FASER
  - Search for long-lived particles and neutrinos
  - Recent detection of neutrinos
- MilliQan
  - Search for milli-charged particles
- MOEDAL
  - Search for magnetic monopoles and other exotic particles
- TOTEM
  - Total cross-section measurements

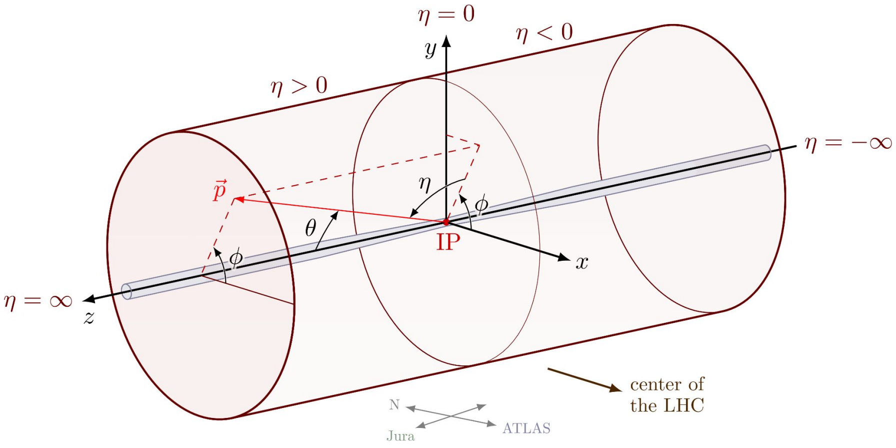

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker



Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Proton
Neutrino
Neutron
Muon
Electron
Photon
The dashed tracks are invisible to the detector

Detector coordinates





https://atlas.cern/Discover/Detector

https://tikz.net/axis3d_cms/

Pseudorapidity

- Rapidity (y) is commonly used in relativistic calculations
  - Differences in y are Lorentz invariant under boosts along z-axis

$$y \equiv \frac{1}{2} \ln\left(\frac{E + p_{\mathrm{L}}}{E - p_{\mathrm{L}}}\right)$$

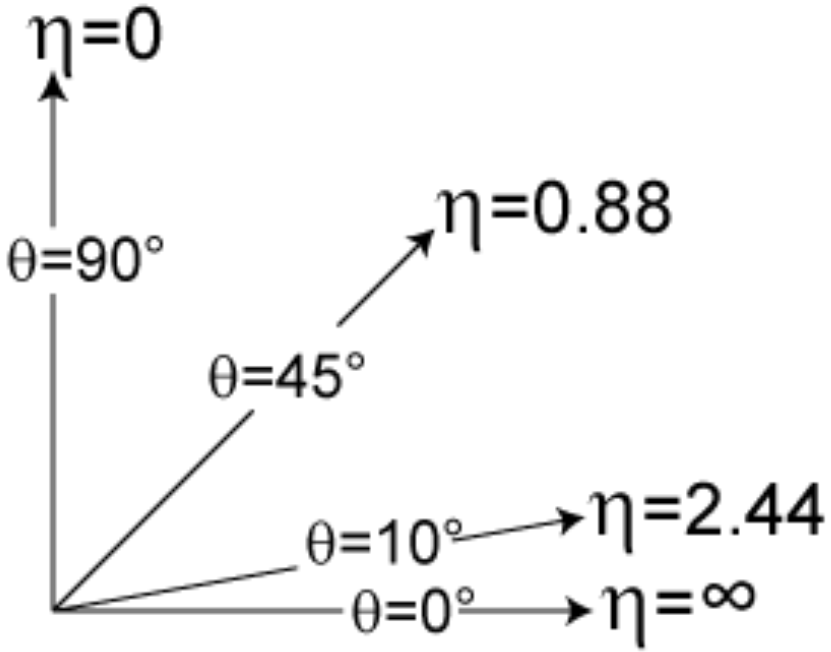
- Pseudorapidity (η) is similar to y for highly relativistic particles
  - Equal to y for massless particles

$$\eta = \frac{1}{2} \ln\left(\frac{|\mathbf{p}| + p_{\mathrm{L}}}{|\mathbf{p}| - p_{\mathrm{L}}}\right)$$

- η is useful because it can be written as a purely geometric quantity
  - Not necessary to fully measure a particle's energy to know its value

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

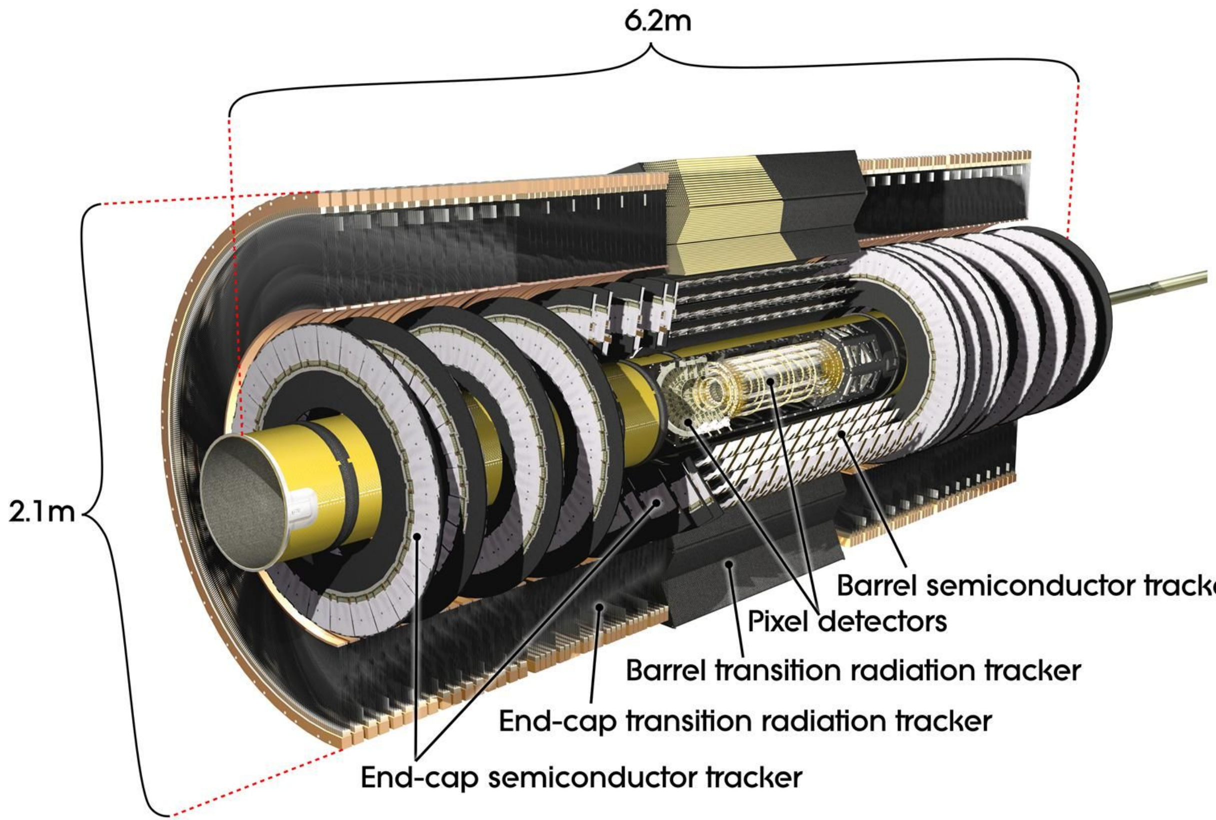
Pseudorapidity



Transverse momentum

- Proton PDFs mean p_z is (essentially) never 0
  - Center-of-mass reference frame is never at rest in lab frame
  - Unknown initial p_z ⇒ conservation of momentum along z-axis cannot be invoked
- Typically measure vector quantities transverse to the beamline
  - Most commonly use transverse momentum - p_T
- Necessary for calculations involving neutrinos and other invisible particles

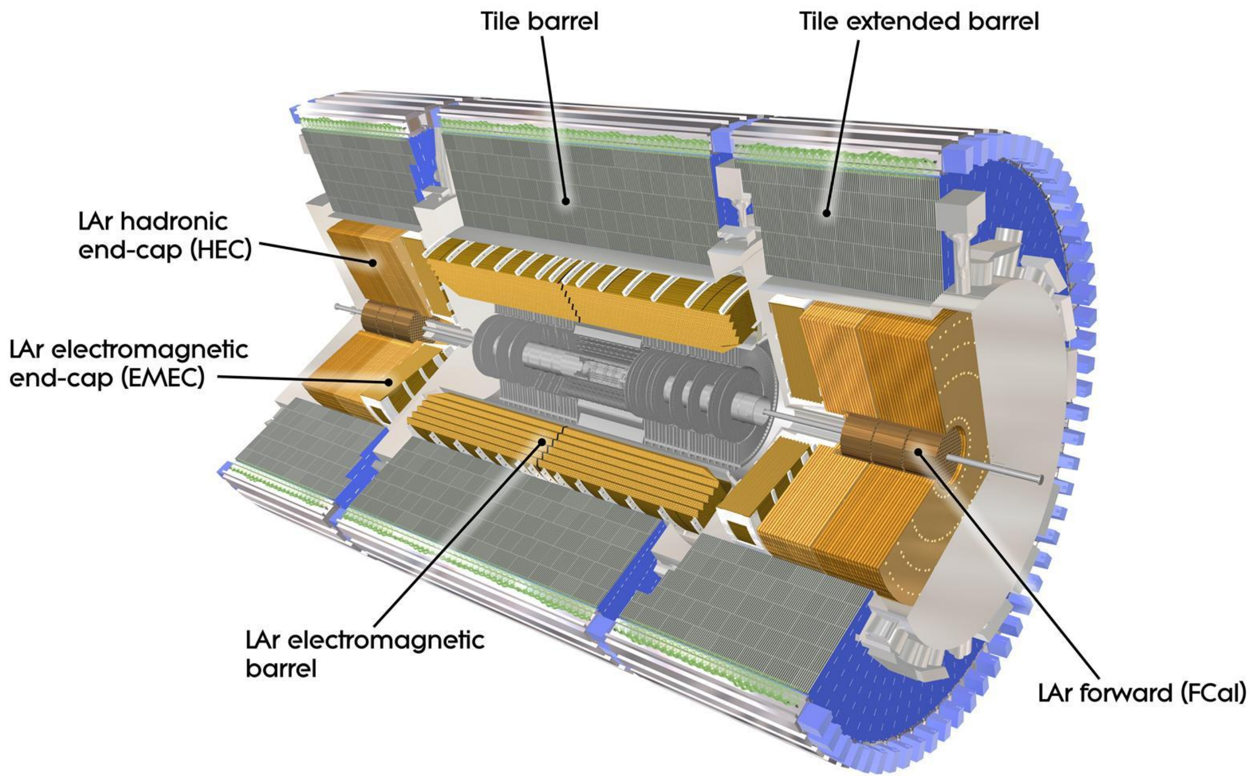
Inner detector



Inner Detector

- Designed to track charged particles close to the interaction point
  - Very high radiation environment
  - Excellent spatial and time resolution necessary
- Pixel detector - innermost layers
  - Fully silicon pixels (50 μm x 400 μm) in 3 layers (barrel and end cap)
  - Provides space points for charged particles passing through
- Strip detector - (SCT)
  - Fully silicon strips (80 μm x 12.8 cm) in 4 barrel layers and 9 end cap layers (each side)
  - Provides space points for charged particles passing through
- Transition Radiation Tracker (TRT)
  - Drift tubes used to identify electrons
- Within magnetic field from solenoid to curve charged particle tracks

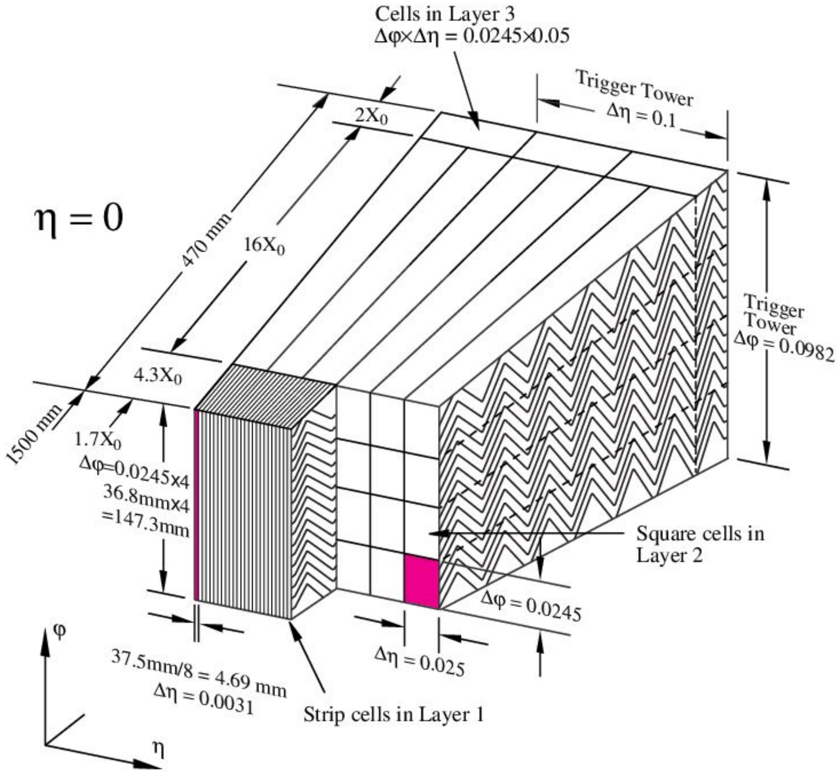
Calorimeters



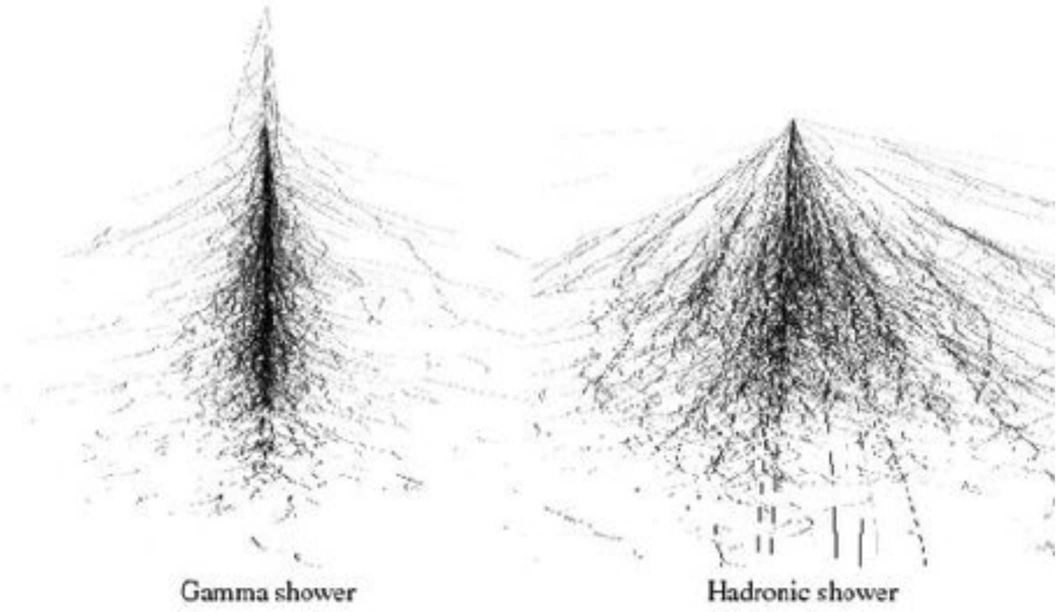
Calorimeters

- Designed to fully stop and measure energy of incident particles
- ATLAS uses sampling calorimeters
  - Dense passive material to promote showering and energy deposition
  - Active material reacts to deposited energy
- Electromagnetic showers - interacting with detector electrons
  - Electrons: bremsstrahlung, e-e scattering, e+e- annihilation, ionization
  - Photons: e+e- pair production, Compton scattering, absorption
  - Short and narrow showers from elastic interactions
- Hadronic showers - interacting with detector nuclei
  - Many complex QCD interactions - inter nuclear cascades, hadron decays, nuclear excitation/de-excitation, spallation, fission
  - Includes some electromagnetic component - from hadron decays and photon emission
  - Wide and deep showers with significant energy lost to inelastic processes

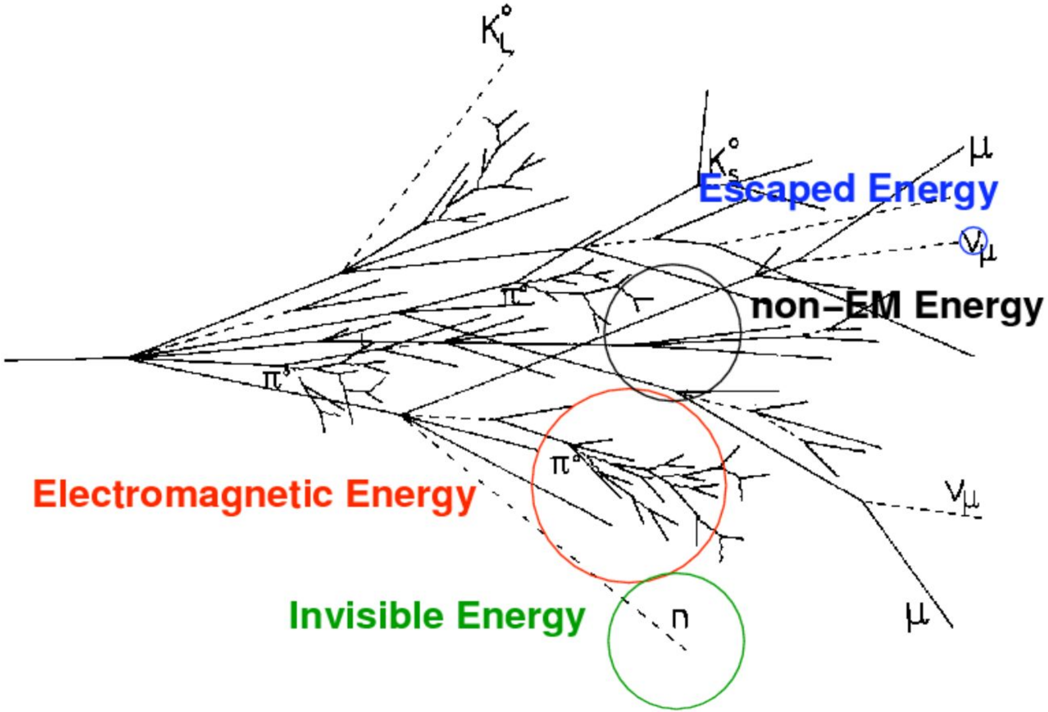
Calorimeters



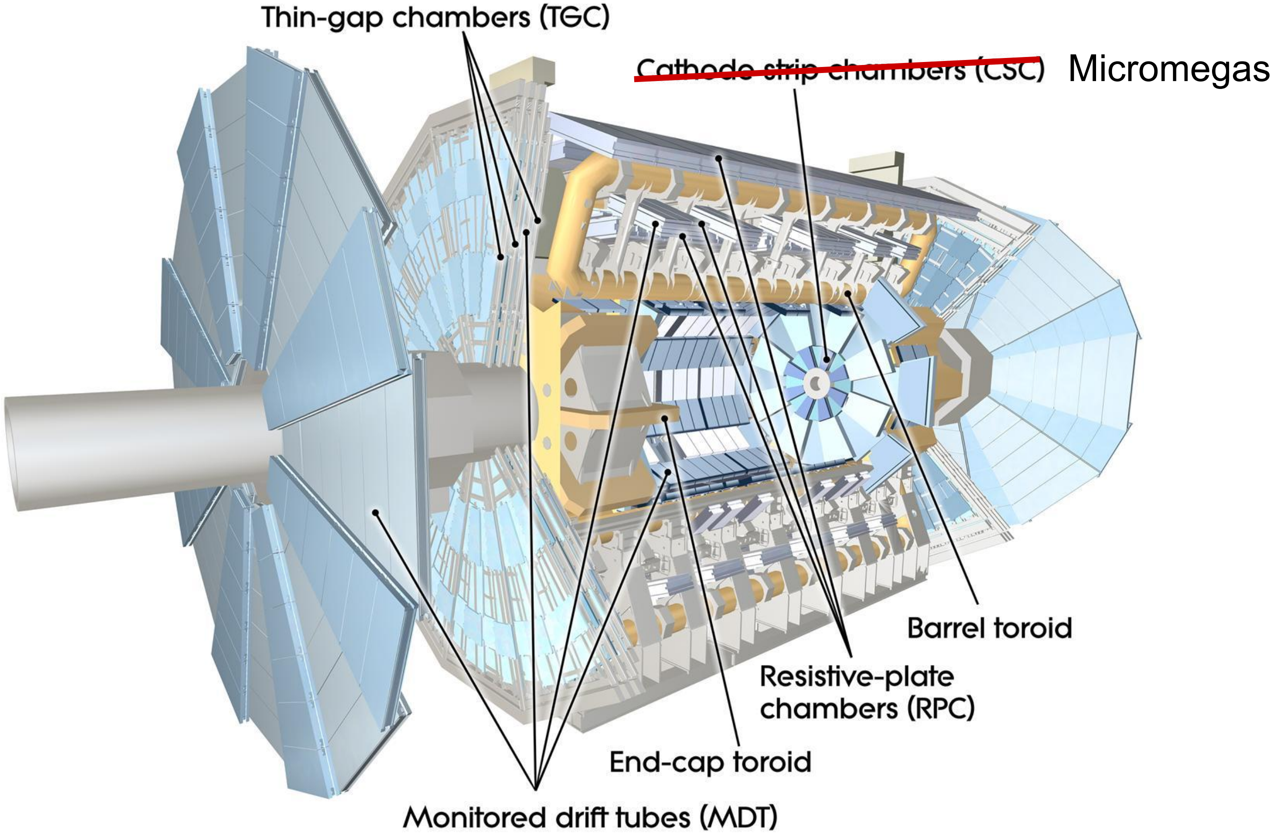
Electromagnetic and hadronic showers



Hadronic showers



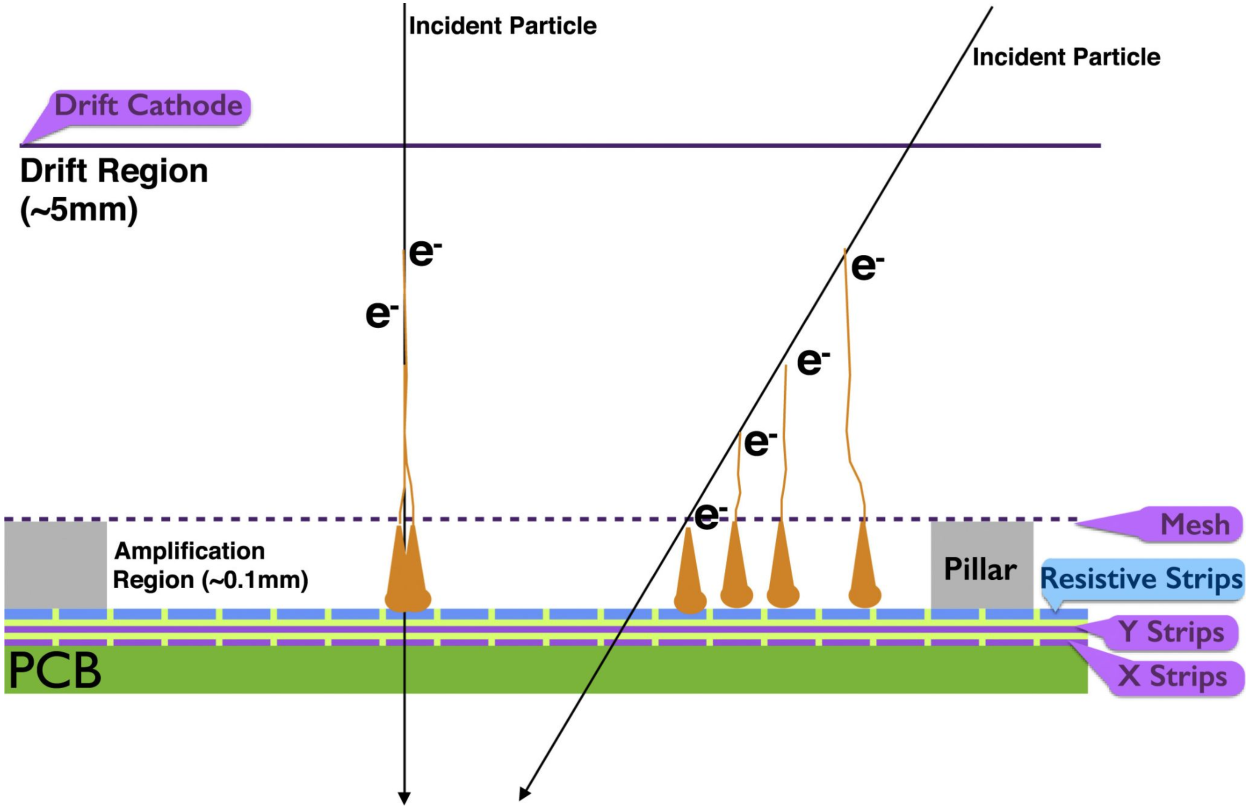
Muon Spectrometer



Muon Spectrometer

- Muons are minimally ionizing particles (MIP)
  - Traverse calorimeters while depositing very little energy
  - Escape the ATLAS detector altogether
- Muon spectrometer forms outer layers of ATLAS
  - Usually only muons reach the system
- Gaseous ionization chamber detector technologies
  - Able to track charged particles
  - Less material cost that silicon detectors
- Charged particles passing through ionize the gas mixture
- Potential difference in chamber creates cascade of electrons amplifying signal
- Induced charge on plates/wires/mesh provide space and time points
- Newer micro-pattern chambers provide very accurate angular measurements
  - Time projection chambers

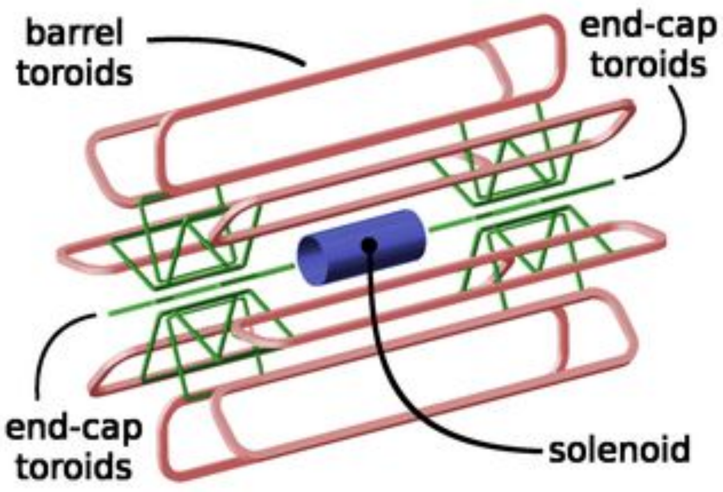
Gaseous ionization chambers



New Small Wheel (NSW)

Magnets

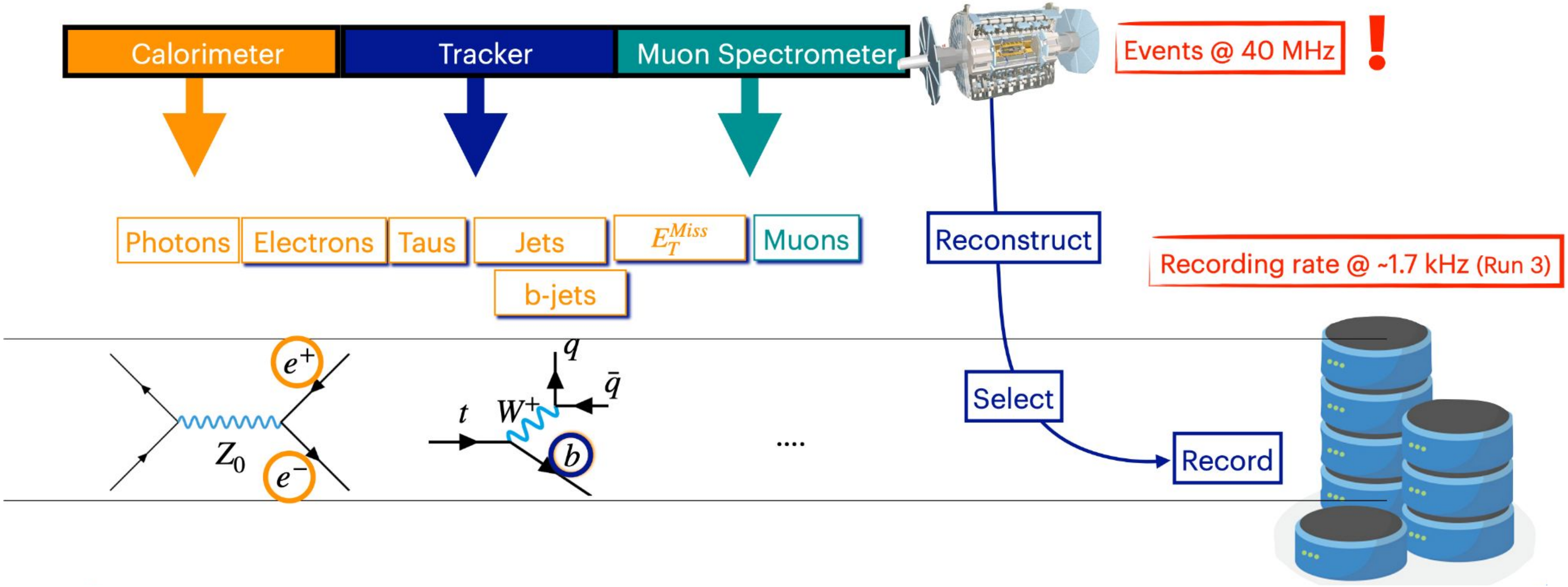
- Magnetic fields used to curve charged particle tracks
  - Allows measurement of charge and momentum
- Solenoid provides field for inner detector
  - 2 T
- Toroids provide field for muon spectrometer
  - ~4 T



Triggers

- Most collisions in ATLAS are not interesting
  - Low-angle elastic scattering is much more common than hard scatter events
- Not feasible to read out or store data from every event
  - Data rates are far beyond the capabilities of our readout electronics
  - Would result in petabytes of data daily - cannot be stored
- Trigger used to automatically select events that may be interesting
  - Events with large deposits of energy in the detector are stored for reconstruction and analysis
- Two-level trigger system
- Level 1 (L1) trigger
  - Hardware-based trigger making coarse decisions about energy deposits
  - 40 MHz ⇒ 100 kHz
- High-Level Trigger (HLT)
  - Software-based trigger making sophisticated decisions about precise signatures
  - 100 kHz ⇒ 1.7 kHz

Triggers



Calorimeter
Tracker
Muon Spectrometer
Events @ 40 MHz
!
Photons
Electrons
Taus
Jets
b-jets
E_T^{Miss}
Muons
Reconstruct
Recording rate @ ~1.7 kHz (Run 3)
Select
Record
e^+
e^-
Z_0
t
W^+
q
$\bar{q}$
b
....